## VI.—*On some recent Evidence of the Variation of the Sun's Heat.*—*By* Henry F. Blanford, *Meteorologist to the Government of India.*

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Since the British Association meeting at Brighton in 1872, at which Mr. Meldrum brought to notice the fact that the Cyclones of the Indian ocean vary in frequency with the period of sun-spot frequency, several attempts have been made to trace out the evidence of a similar periodicity in other meteorological phenomena. Mr. Meldrum and Mr. Norman Lockyer have done this in the case of the rainfall, with the result of shewing that in the Mauritius, Australia, South Africa and some other parts of the world such a variation is to be detected more or less distinctly in the registers. And Professor Köppen has arrived at a similar conclusion in the case of air temperature, a result on which I shall have again to offer some remarks in the sequel. All these results point to the conclusion that the radiation of the sun is not appreciably constant from year to year,* but varies with the appearance and physical state of his surface.

Long prior to any of these discoveries, the possible variation of the sun's heat and of its influence on the earth had been the subject of speculation among solar physicists. According to Professor Wolf, (as quoted by Professor Köppen,) Riccioli, in 1651, shortly after the first discovery of sun-spots, surmised that some coincidence might exist between them and terrestrial weather changes. Sir William Herschell endeavoured to establish such a connexion by discussing one of their remote effects, *viz.*, the rise and fall in the price of wheat in past years. Sabine established a connexion between the solar-spot period and that of magnetic storms; Fritz between the former and the frequency of auroras; and finally, in 1867, Mr. Joseph Baxendell of Manchester succeeded in tracing out a distinct and very striking relation between the number of the sun spots, and the ratio that exists between the difference of the mean maximum temperature of solar radiation and the mean maximum air temperature on the one hand, and that of the mean temperatures of the air and of evaporation on the other.

All these investigations, it will be noticed, have dealt with the problem in an indirect form: that of Mr. Baxendell being, however, the most direct, and perhaps as direct as the data at his command (six years observations of the Radcliffe observatory, and five years of Mr. Mackereth's register at Eccles near Manchester) would admit of. The causes that interfere with the direct transmission of the sun's heat to the earth's surface are so powerful and at the same time so variable, that even with more perfect instruments than

* As was assumed by Mr. Meech in his elaborate treatise on Solar heat in the IXth Volume of the "Smithsonian Contributions to Knowledge."

we possess at present, it is not to be expected that in English latitudes and under her variable and cloudy skies, the temperature of the solar heat incident on the earth's surface, recorded at two stations only, should coincide at all distinctly in variation with that of the heat emitted from the sun. Still, by a very ingenious treatment of the data, Mr. Baxendell succeeded in shewing, with great probability, that the sun's radiation varied in intensity directly with the observed number of the spots during the years 1859 to 1866.

It was still desirable, however, that further and more direct proof should be obtained, and it is obvious that for such a purpose, no country offers more favourable conditions than India; and fortunately, owing in no small degree to the urgent representations of this Society in past years, the means provided by the Government of Bengal, in the establishment of systematic observations throughout its provinces, have put it in my power to bring before the Society this evening, evidence, which if not absolutely conclusive, at least leaves, I think, but little room for doubt, that the old speculations are true; and that the sun's heat varies from year to year, to such an extent as must appreciably affect terrestrial phenomena.

Registers of the readings of a maximum thermometer, the bulb of which is coated with lamp-black and which is enclosed in an exhausted tube,* were commenced at a few stations in Bengal in the latter part of 1867 or the beginning of 1868; at others the observations were begun in subsequent years. The instruments are freely exposed to the sun's rays, supported on forked sticks at a height of one foot above the ground† and their readings have been recorded on all days, whether clear or cloudy. Being very fragile, and exposed without protection, they are unfortunately very subject to breakage, and although therefore their registers extend in most cases over a period of six or seven years, I can find but one station on my list at which the register has been kept continuously for more than five years with one and the same instrument. This fact very much reduces the quantity of data available for discussion. It appears that, from some cause at present unexplained, these thermometers, made by the best London makers, sometimes differ in their readings to the extent of several degrees (I have known differences of 10° and 15°) when exposed under apparently identical circumstances; and there have been hitherto no means of comparing them together in Calcutta in the only effectual way, *viz.*, by exposing them side by side to the solar radiation, and correcting all to some one instrument, arbitrarily selected as a standard. In dealing with the registers then, I

* In one of these tubes which I opened, (that of a thermometer by Messrs. Negretti and Zambra,) I found the residual air to have a pressure at the freezing point of 1·26 ins. about equal to a vacuum of $\frac{1}{24}$.

† At Roorkee the instrument is about 4 feet above the ground.

have been obliged to restrict my comparison to those of consecutive years that have been recorded with the same instrument, and wherever an instrument has lasted over a single twelvemonth only or less, its register has been totally set aside.

The next precaution necessary is to eliminate as far as possible from the individual registers, those irregularities which are due to variations in the state of the sky. This, however, can be done but very imperfectly, otherwise than on the mean of a very large number of observations. It results from the actinometric observations of Pouillet, Kämtz, Quetelet and Althaus, that with a vertical sun, and a sky free from all visible cloud or haze, the proportion of solar heat that penetrates the whole thickness of the atmosphere, and is therefore effective at sea-level, does not amount to more than two-thirds or at the utmost three-fourths of that which reaches the exterior of our atmosphere. Herschell estimates it at the former quantity. But in India, the atmosphere, when cloudless to the eye, is by no means so diathermanous as is here assumed. Sometimes for many days together, with settled weather and a cloudless sky, the sun thermometer gives steady maximum readings, not differing more than one or two degrees. A day follows on which there is a good deal of cloud, and perhaps some rain, and the diathermancy of the atmosphere is so increased in the intervals of the clouds, that the sun-thermometer registers 10° or 15° above any of its previous readings. Such cases occur frequently in all the registers. It is probable therefore that on days registered as cloudless, not less than half the solar radiation and frequently much more is absorbed by the atmosphere. In order to obtain data that shall be fairly comparable, I have in most cases selected those days on which the sky was either cloudless at 10 A. M. and 4 P. M., or had on the average not more than one-fifth of cloud. In the case of the two comparatively cloudy stations Silchar and Port Blair, I have been obliged to extend these limits; in the former case to three tenths, in the latter to one half. The monsoon months, June to September, are omitted in these tables.

Another method of proceeding which I have adopted in order to verify these results is to take the two highest readings recorded in each month (including the monsoon months) as the data for comparison.

The four following tables give the results. In Tables I. and II. the comparison is restricted to the registers of those stations and years in which the same instrument has been read continuously for at least two consecutive calendar years. The differences of each pair of years are given separately for each station, and the means of the whole. This method of comparison, however, admits of a very small portion only of the data being utilized, since it excludes all broken years, and therefore in Tables III. and IV. I have adopted a modified course of proceeding, which admits these.

I have taken first for each station separately the temperature differences of each pair of homonymous months in consecutive years, rejecting as before all those in which the instrument has been changed in the interval; and next the mean of all the differences thus obtained for the same pair of months. A rise of temperature is indicated by +, a fall by —.

Table I.—*Differences of annual means of black-bulb temperatures with a clear sky (as above defined).*

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair. | | +2·2 | | | | —1·7 |
| Cuttack, | | | | +1·8 | +1·4 | 0 |
| Chittagong, | | | | —0·8 | —1·9 | 0 |
| Dacca, | | | | +2·6 | —2·2 | —0·4 |
| Hazaribagh, | +2·9 | +1·9 | | | | —4·4 |
| Berhampore, | | | | | | —2·4 |
| Patna, | +7·7 | | | | | |
| Monghyr, | | +2·9 | —0·1 | | | |
| Silchar, | | | —2·1 | 0 | —1·8 | +6·3 |
| Roorkee, | | | +2·3 | | | —5·6 |
| Sums, | +10·6 | +7·0 | +0·1 | +3·6 | —4·5 | —8·2 |
| Means, | +5·3 | +2·3 | 0 | +0·9 | —1·1 | —1·0 |

Table II.—*Differences of annual means of two highest black bulb temperatures monthly.*

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | +2·9 | | | | —1·3 |
| Cuttack, | | | | +2·6 | +2·5 | —2·3 |
| Chittagong, | | | | —1·7 | —0·4 | +1·3 |
| Dacca, | | | | +1·7 | —1·2 | +1·2 |
| Hazaribagh, | +2·8 | +3·7 | | | | —3·9 |
| Berhampore, | | | | | | —1·2 |
| Patna, | +6·0 | | | | | |
| Monghyr, | | +0·3 | —1·0 | | | |
| Silchar, | | | +1·8 | —2·3 | —0·3 | +7·7 |
| Roorkee, | | | —0·9 | | | —3·9 |
| Sums, | +8·8 | +6·9 | —0·1 | +0·3 | +0·6 | —2·4 |
| Means, | +4·4 | +2·3 | 0 | +0·1 | +0·1 | —0·3 |

TABLE III. A.—*Differences of monthly means of black-bulb temperatures with clear sky.*

JANUARY.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | — 1·3 | + 3·3 | | | — 8·2 |
| Cuttack, | | | | — 5·0 | + 8·3 | — 0·6 |
| Chittagong, | | | | — 2·5 | — 3·0 | — 1·5 |
| Jessore, | + 1·7 | | | | | |
| Dacca, | | | | — 1·0 | — 2·6 | — 3·2 |
| Hazaribagh, | — 3·5 | + 5·9 | — 1·0 | | | — 5·5 |
| Berhampore, | | — 2·9 | | — 3·4 | | — 11·8 |
| Silchar, | | | + 2·3 | — 5·1 | — 1·0 | 0 |
| Monghyr, | | + 1·5 | + 3·8 | — 4·7 | | |
| Patna, | + 6·7 | + 8·6 | | | | |
| Roorkee, | | | — 3·1 | — 5·2 | | — 12·0 |
| Means, | + 1·6 | + 2·4 | + 1·3 | — 3·8 | + 0·4 | — 5·3 |

FEBRUARY.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | — 2·7 | + 4·9 | | | — 2·5 |
| Cuttack, | | | | — 5·0 | + 7·2 | — 1·4 |
| Chittagong, | | | | — 4·7 | — 0·7 | + 0·5 |
| Jessore, | + 1·6 | | | | | |
| Dacca, | | | | — 1·7 | — 0·5 | — 3·3 |
| Hazaribagh, | + 2·2 | + 2·5 | + 3·9 | | | — 0·8 |
| Berhampore, | | — 4·2 | | — 5·1 | | — 11·3 |
| Silchar, | | | + 0·5 | — 5·1 | + 2·4 | 0 |
| Monghyr, | | + 3·2 | + 1 5 | — 4·8 | | |
| Patna, | + 20·2 | — 3·4 | | | | |
| Roorkee, | | | — 6·8 | — 0·2 | | — 9·7 |
| Means, | + 8·0 | — 0·9 | + 0·8 | — 3·8 | + 2·1 | — 3·6 |

MARCH.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | + 5·4 | + 2·8 | | | — 7·1 |
| Cuttack, | | | | — 4·8 | + 4·0 | + 0·2 |
| Chittagong, | | | | + 0·5 | — 0·4 | — 1·5 |
| Jessore, | + 2·7 | | | | | |
| Dacca, | | | | + 4·3 | — 2·1 | + 0·2 |
| Hazaribagh, | + 5·0 | — 2·3 | + 8·2 | | — 3·4 | — 4.7 |
| Berhampore, | | + 1·6 | | — 3·1 | | + 13·1 |
| Silchar, | | | — 1·5 | — 1·9 | — 1·4 | + 1·9 |
| Monghyr, | | — 0·4 | + 3·6 | — 1·5 | | |
| Patna, | + 19·2 | | | | | |
| Roorkee, | | | + 0·9 | — 9·3 | | — 15·3 |
| Means, | + 9·0 | + 1·1 | + 2·8 | — 2·3 | — 0·7 | — 1·7 |

### April.

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | +3·8 | —3·2 | | | +1·0 |
| Cuttack, | | | —0·6 | +2·7 | —3·9 | +2·3 |
| Chittagong, | | | —0·2 | +1·8 | —2·0 | —1·7 |
| Jessore, | +4·2 | | | | | |
| Dacca, | | | —4·0 | +5·1 | —2·9 | 0 |
| Hazaribagh, | +10·0 | —2·1 | +1·7 | | —6·3 | —6·2 |
| Berhampore, | | +3·6 | | —7·3 | | +5·7 |
| Silchar, | | | —3·5 | +1·4 | —6·0 | +5·3 |
| Monghyr, | | —0·3 | +1·9 | —2·5 | | |
| Patna, | +8·4 | | | | | |
| Roorkee, | | | +6·1 | | +5·6 | —8·1 |
| Means, | +7·5 | +1·1 | —0·2 | +0·2 | —2·6 | —0·2 |

### May.

| | | | | | | |
|---|---|---|---|---|---|---|
| Port Blair, | | —0·7 | —3·9 | | | —7·7 |
| Cuttack, | | | —5·9 | +9·7 | —5·5 | —1·9 |
| Chittagong, | | | +3·7 | —5·6 | —1·8 | —0·2 |
| Jessore, | | | | | | |
| Dacca, | | | —6·7 | +5·4 | —3·7 | +0·1 |
| Hazaribagh, | +14·2 | —6·6 | +2·6 | | —2·6 | —4·4 |
| Berhampore, | | +9·9 | | | +5·0 | —7·2 |
| Silchar, | | | —1·9 | +1·0 | —3·2 | +5·9 |
| Monghyr, | | +1·7 | —4·6 | | | |
| Patna, | +3·9 | | | | | |
| Roorkee, | | | —1·1 | | +6·7 | —4·9 |
| Means, | +9·1 | +1·1 | —2·2 | +2.6 | —0·7 | —2·5 |

### October.

| | | | | | | |
|---|---|---|---|---|---|---|
| Port Blair, | — 1·7 | — 8·0 | | | — 8·8 | + 4·0 |
| Cuttack, | | | — 3·8 | + 4·0 | + 0·2 | + 2·5 |
| Chittagong, | | | — 5·5 | + 4·1 | — 4·3 | + 2·4 |
| Jessore, | | + 6·0 | | | | |
| Dacca, | | | — 0·6 | + 2·5 | — 2·3 | + 4·7 |
| Hazaribagh, | — 7·0 | +10·6 | | | — 6·9 | — 4·1 |
| Berhampore, | | | + 0·3 | | —12·7 | — 1·9 |
| Silchar, | | | — 4·0 | + 4·6 | — 1·3 | + 6·4 |
| Monghyr, | — 4·4 | + 9·0 | — 2·9 | | | |
| Patna, | — 5·0 | | | | | |
| Roorkee, | | | + 4·6 | | — 1·3 | + 3·8 |
| Means, | — 4·5 | + 8·4 | — 1·7 | + 4·0 | — 4·7 | + 2·7 |

NOVEMBER.

| STATIONS. | 1868-9. | 1869-70. | 1870-1. | 1871-2. | 1872-3. | 1873-4. |
|---|---|---|---|---|---|---|
| Port Blair, | — 6·4 | + 0·8 | | | — 2·1 | + 2·1 |
| Cuttack, | | | — 0·5 | + 4·6 | + 1·2 | — 1·8 |
| Chittagong, | | | — 2·3 | — 0·5 | — 1·8 | + 3·1 |
| Jessore, | | + 5·7 | | | | |
| Dacca, | | | + 0·1 | + 4·6 | — 1·9 | — 0·8 |
| Hazaribagh, | — 1·2 | + 4·8 | | | — 3·6 | — 7·9 |
| Berhampore, | — 0·5 | | + 1·9 | | —13·4 | — 4·3 |
| Silchar, | | | — 5·9 | + 5·4 | — 4·0 | +15·4 |
| Monghyr, | — 2·8 | + 3·9 | — 0·8 | | | |
| Patna, | — 0·3 | | | | | |
| Roorkee, | | — 9·6 | + 3·1 | | — 3·5 | + 0·3 |
| Means, | — 2·2 | + 1·3 | — 0·6 | + 3·5 | — 3·6 | + 0·8 |

DECEMBER.

| STATIONS. | 1868-9. | 1869-70. | 1870-1. | 1871-2. | 1872-3. | 1873-4. |
|---|---|---|---|---|---|---|
| Port Blair, | — 1·7 | + 4·8 | | | — 4·8 | + 4·6 |
| Cuttack, | | | — 2·5 | + 6·2 | + 1·7 | — 1·4 |
| Chittagong, | | | — 2·6 | + 0·3 | — 0·7 | — 1·4 |
| Jessore, | | + 2·8 | | | | |
| Dacca, | | | + 0·2 | + 2·0 | — 2·3 | — 0·4 |
| Hazaribagh, | + 3·4 | + 2·1 | | | — 0·4 | — 5·7 |
| Berhampore, | — 4·8 | | — 0·7 | | —10·9 | — 5·1 |
| Silchar, | | | — 3·4 | + 0·2 | — 0·3 | +15·5 |
| Monghyr, | + 0·5 | + 4·3 | — 3·5 | | | |
| Patna, | + 8·5 | | | | | |
| Roorkee, | | — 2·6 | + 1·3 | | — 5·3 | + 1·3 |
| Means, | + 1·2 | + 2·3 | — 1·6 | + 2·2 | — 2·9 | + 0·9 |

TABLE III. B.—*Mean monthly and annual differences of black-bulb temperatures with a clear sky.*

| MONTHS. | 1868-9. | 1869-70. | 1870-1. | 1871-2. | 1872-3. | 1873-4. |
|---|---|---|---|---|---|---|
| January, | + 1·6 | + 2·4 | + 1·3 | — 3·8 | + 0·4 | — 5·3 |
| February, | + 8·0 | — 0·9 | + 0·8 | — 3·8 | + 2·1 | — 3·6 |
| March, | + 9·0 | + 1·1 | + 2·8 | — 2·3 | — 0·7 | — 1·7 |
| April, | + 7·5 | + 1·1 | — 0·2 | + 0·2 | — 2·6 | — 0·2 |
| May, | + 9·1 | + 1·1 | — 2·2 | + 2·6 | — 0·7 | — 2·5 |
| October, | — 4·5 | + 8·4 | — 1·7 | + 4·0 | — 4·7 | + 2·7 |
| November, | — 2·2 | + 1·3 | — 0·6 | + 3·5 | — 3·6 | + 0·8 |
| December, | + 1·2 | + 2·3 | — 1·6 | + 2·2 | — 2·9 | + 0·9 |
| Sums, | +29·7 | +16·8 | — 1·4 | + 2·6 | —12·7 | — 8·9 |
| Means, | + 3·7 | + 2·1 | — 0·2 | + 0·3 | — 1·6 | — 1·1 |

TABLE IV. A.—*Differences of monthly means of two highest black-bulb temperatures in consecutive years.*

JANUARY.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | | 0 | — 1·0 | | | — 13·0 |
| Cuttack, ................. | | | | — 3·5 | + 7·8 | — 0·1 |
| Chittagong, ............ | | | | — 2·0 | — 1·3 | + 1·4 |
| Jessore, ................. | + 1·0 | | | | | |
| Dacca, .................... | | | | + 0·6 | — 0·9 | — 4·7 |
| Hazaribagh, ............ | — 3·0 | + 9·0 | — 2·5 | | .. | — 4·0 |
| Berhampore, ............ | | — 5·7 | | — 3·2 | .... | — 8·5 |
| Silchar, ................. | | | — 3·0 | — 3·0 | + 4·5 | + 1·0 |
| Monghyr, ............... | | + 2·5 | — 2·0 | — 1·0 | | |
| Patna, .................... | + 17·0 | — 7·0 | | | | |
| Roorkee, ................. | | | + 2·0 | — 4·0 | | — 10·1 |
| Sums, | + 15·0 | — 1·2 | — 6·5 | — 16·1 | + 10·1 | — 38·0 |
| Means, | + 5·0 | — 0·2 | — 1·3 | — 2·3 | + 2·5 | — 4·7 |

FEBRUARY.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | | — 3·0 | — 1·0 | | | — 5·0 |
| Cuttack, ................. | | | | — 7·2 | + 7·4 | — 2·3 |
| Chittagong, ............ | | | | — 8·6 | — 1·4 | + 4·6 |
| Jessore, ................. | + 3·4 | | | | | |
| Dacca, .................... | .. | | | — 0·6 | + 0·6 | + 0·6 |
| Hazaribagh, ............ | + 9·0 | — 2·5 | + 3·5 | | | — 3·0 |
| Berhampore, ............ | | — 6·7 | | — 0·2 | | — 10·7 |
| Silchar, ................. | | | — 0·5 | — 3·5 | + 2·0 | — 1·0 |
| Monghyr, ............... | | + 0·5 | + 3·5 | — 10·5 | | |
| Patna, .................... | + 20·0 | | | | | |
| Roorkee, ................. | | | — 9.5 | + 4·5 | | — 10·8 |
| Sums, | + 32·4 | — 11·7 | — 4·0 | — 26·1 | + 8·6 | — 24·6 |
| Means, | + 10·8 | — 2·9 | — 0·8 | — 3·7 | + 2·1 | — 3·1 |

MARCH.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | | + 6·5 | + 1·0 | | | — 5·5 |
| Cuttack, ................. | | | | + 0·5 | + 0·2 | — 2·3 |
| Chittagong, ............ | | | | + 2·0 | — 1·2 | + 0·2 |
| Jessore, ................. | — 2·5 | | | | | |
| Dacca, .................... | | | | + 4·1 | — 3·5 | — 0·6 |
| Hazaribagh, ............ | + 2·0 | + 7·5 | + 1·0 | | — 3·7 | — 6·0 |
| Berhampore, ............ | | + 5·7 | | — 2·5 | | — 6·7 |
| Silchar, ................. | | | — 1·0 | — 6·0 | — 3·0 | + 4·5 |
| Monghyr, ............... | | + 1·0 | + 2·5 | — 3·5 | | |
| Patna, .................... | + 12·5 | | | | | |
| Roorkee, ................. | | | + 0·5 | + 4·2 | | — 9·6 |
| Sums, | + 10·0 | + 25·7 | + 4·0 | — 1·2 | — 11·2 | — 26·0 |
| Means, | + 3·3 | + 6·4 | + 0·8 | — 0·2 | — 2·2 | — 3·2 |

### April.

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | + 5·0 | — 3·0 | | | — 2·5 |
| Cuttack, | | | + 1·0 | — 3·2 | — 0·4 | + 3·0 |
| Chittagong, | | | + 5·6 | — 3·5 | — 2·0 | + 1·7 |
| Jessore, | — 0·5 | | | | | |
| Dacca, | | | + 1·4 | + 3·2 | — 4·2 | + 1·4 |
| Hazaribagh, | + 10·5 | 0 | + 2·0 | | — 7·5 | — 4·0 |
| Berhampore, | | + 2·2 | | — 6·7 | | — 6·7 |
| Silchar, | | | — 5·5 | — 4·5 | — 4·5 | + 10·0 |
| Monghyr, | | — 3·5 | + 1·5 | 0 | | |
| Patna, | + 2·5 | | | | | |
| Roorkee, | | | + 1·5 | — 3·7 | | — 7·1 |
| Sums, | + 12·5 | + 3·7 | + 4·5 | — 18·4 | — 18·6 | — 4·2 |
| Means, | + 4·2 | + 0·9 | + 0·6 | — 2·6 | — 3·7 | — 0·5 |

### May.

| | | | | | | |
|---|---|---|---|---|---|---|
| Port Blair, | | + 3·5 | — 2·5 | | | — 5·0 |
| Cuttack, | | | — 7·0 | + 4·0 | — 1·5 | + 1·9 |
| Chittagong, | | | — 1·0 | — 4·2 | + 6·6 | — 6·9 |
| Jessore, | | | | | | |
| Dacca, | | | — 3·1 | + 1·6 | + 0·4 | — 1·9 |
| Hazaribagh, | + 7·5 | + 1·5 | — 6·0 | | — 8·0 | — 1·2 |
| Berhampore, | | + 7·5 | | + 1·2 | + 8·0 | — 2·0 |
| Silchar, | | | + 8·5 | — 2·0 | — 6·5 | + 8·5 |
| Monghyr, | | + 3·0 | — 7·0 | | | |
| Patna, | + 0·5 | | | | | |
| Roorkee, | | | — 2·0 | | — 1·0 | + 2·4 |
| Sums, | + 8·0 | + 15·5 | — 20·1 | + 0·6 | — 2·0 | — 4·2 |
| Means, | + 4·0 | + 3·9 | — 2·5 | + 0·1 | — 0·3 | — 0·5 |

### June.

| | | | | | | |
|---|---|---|---|---|---|---|
| Port Blair, | | + 14·0 | | | | + 6·5 |
| Cuttack, | | | — 14·0 | + 9·0 | + 15·0 | — 19·0 |
| Chittagong, | | | — 2·5 | + 2·1 | — 2·3 | + 5·4 |
| Jessore, | | | | | | |
| Dacca, | | | + 2·5 | + 1·1 | + 0·1 | + 2·4 |
| Hazaribagh, | + 3·5 | + 7·5 | — 4·5 | | — 4·5 | — 12·0 |
| Berhampore, | + 3·0 | + 4·0 | | | + 4·2 | — 0·5 |
| Silchar, | | | + 17·5 | — 1·5 | — 7·5 | + 14·5 |
| Monghyr, | + 5·0 | + 5·0 | — 3·5 | | | |
| Patna, | + 4·0 | | | | | |
| Roorkee, | | | — 4·0 | | + 1·5 | — 6·3 |
| Sums, | + 15·5 | + 30·5 | — 8·5 | + 10·7 | + 6·5 | — 9·0 |
| Means, | + 3·9 | + 7·6 | — 1·2 | + 2·7 | + 0·9 | — 1·1 |

JULY.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | + 3·0 | | | | + 11·0 |
| Cuttack, | | | + 1·5 | — 3·5 | — 0·2 | + 4·9 |
| Chittagong, | | | — 1·4 | — 4·5 | — 3·4 | + 3·7 |
| Jessore, | | | | | | |
| Dacca, | | | + 3·1 | + 0·1 | — 5·7 | + 4·1 |
| Hazaribagh, | — 5·0 | + 7·0 | — 8·0 | | — 4·2 | — 2·2 |
| Berhampore, | + 0·5 | | — 3·5 | | + 1·7 | — 4·5 |
| Silchar, | | | + 9·5 | — 3·5 | — 1·0 | + 7·5 |
| Monghyr, | — 2·0 | — 2·0 | + 0·5 | | | |
| Patna, | — 4·5 | | | | | |
| Roorkee, | | | — 3·0 | | + 11·1 | — 12·1 |
| Sums, | — 11·0 | + 8·0 | — 1·3 | — 11·4 | — 1.7 | + 12·4 |
| Means, | — 2·8 | + 2·7 | — 0·2 | — 2·8 | — 0 2 | + 1·5 |

AUGUST.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | + 3·0 | | | | — 9.5 |
| Cuttack, | | | — 2·2 | + 2·2 | + 0.9 | + 0·6 |
| Chittagong, | | | — 0·9 | — 3·6 | + 3.6 | + 1·3 |
| Jessore, | | | | | | |
| Dacca, | | | 0 | + 7·0 | — 0·9 | + 2·4 |
| Hazaribagh, | + 0·5 | — 2·0 | + 0·5 | | — 9·5 | + 2.2 |
| Berhampore, | + 10·0 | | — 2·7 | | — 7·0 | + 3·5 |
| Silchar, | | | — 2·0 | — 3·0 | + 7·0 | + 5·5 |
| Monghyr, | + 5·0 | — 5·0 | + 1·0 | | | |
| Patna, | + 16·5 | | | | | |
| Roorkee, | | | — 0·6 | | + 2·8 | — 1·2 |
| Sums, | + 32·0 | — 4·0 | — 6·9 | + 2·6 | — 3·1 | + 4·8 |
| Means, | + 8·0 | — 1·3 | — 0·9 | + 0·6 | — 0·4 | + 0·6 |

SEPTEMBER.

| STATIONS. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, | | — 3·5 | | | — 2·0 | + 3·0 |
| Cuttak | | | — 5·7 | + 14·4 | — 10·9 | + 3·7 |
| Chittagong, | | | — 3·0 | + 0·4 | + 1·7 | — 1·4 |
| Jessore, | | — 5·0 | | | | |
| Dacca, | | | — 4·9 | + 2·0 | — 1·6 | + 8.1 |
| Hazaribagh, | + 1·5 | + 6·5 | | | — 10·5 | + 0.5 |
| Berhampore, | — 1·5 | | — 1·0 | | — 9·7 | + 5·5 |
| Silchar, | | | + 8·0 | — 3·0 | + 6·5 | + 2·0 |
| Monghyr, | + 6·5 | — 5·5 | — 1·0 | | | |
| Patna, | + 6·5 | | | | | |
| Roorkee, | | | + 1·5 | | + 3·1 | + 1·0 |
| Sums, | + 13·0 | — 7·5 | — 6·1 | + 13·8 | — 23·4 | + 22·4 |
| Means, | + 3·3 | — 1·9 | — 0·9 | + 3·4 | — 2·9 | + 2·8 |

### October.

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | — 1·0 | + 6·0 | | | + 0·5 | 0 |
| Cuttack, ............... | | | — 4·0 | + 7·5 | — 0·9 | + 0·1 |
| Chittagong, ............ | | | — 0·4 | — 0·5 | — 1·7 | + 4·0 |
| Jessore, ............... | | — 2·1 | | | | |
| Dacca, ................. | | | — 3·4 | + 0·4 | — 0·1 | + 2·9 |
| Hazaribagh, ............ | — 5·5 | + 7·0 | | | + 1·5 | — 7·5 |
| Berhampore, ............ | + 8·0 | | — 1·0 | | — 11·2 | + 4·0 |
| Silchar, ............... | | | + 8·0 | — 11·0 | + 2·5 | + 15·5 |
| Monghyr, ............... | + 0·5 | + 3·0 | — 3·0 | | | |
| Patna, ................. | + 1·5 | | | | | |
| Roorkee, ............... | | | — 0·5 | | + 0·7 | + 2·7 |
| Sums, | + 3·5 | + 13·9 | — 2·3 | — 3·6 | — 8·7 | + 21·7 |
| Means, | + 0·7 | + 3·5 | — 0·3 | — 0·9 | — 1·1 | + 2·7 |

### November.

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | — 5·5 | + 2·0 | | | — 3·0 | + 4·0 |
| Cuttack, ............... | | | —13·0 | + 9·2 | + 0·8 | — 4·7 |
| Chittagong, ............ | | | — 4·8 | + 7·4 | — 3·9 | + 3·9 |
| Jessore, ............... | | + 7·9 | | | | |
| Dacca, ................. | | | 0 | — 0·6 | + 1·6 | + 5·6 |
| Hazaribagh, ............ | 0 | + 6·5 | | | — 4·7 | — 4·2 |
| Berhampore, ............ | + 1·5 | | — 3·5 | | —12·0 | + 2·0 |
| Silchar, ............... | | | — 4·5 | + 3·5 | — 1·5 | +14·5 |
| Monghyr, ............... | — 6·5 | + 5·5 | — 1·5 | | | |
| Patna, ................. | — 2·0 | | | | | |
| Roorkee, ............... | | — 7·5 | 0 | | — 4·1 | + 4·3 |
| Sums, | —12·5 | +14·4 | —27·3 | +19·5 | —26·8 | +25·4 |
| Means, | — 2·5 | + 2·9 | — 3·9 | + 4·9 | — 3·3 | + 3·2 |

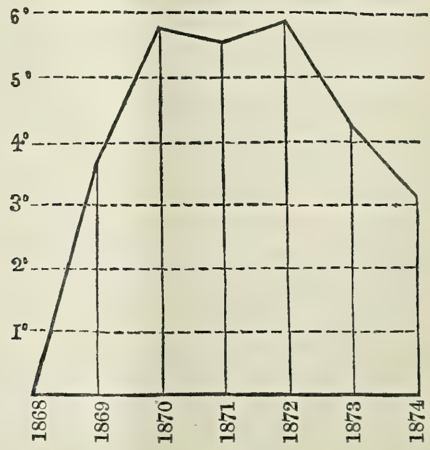
### December.

| Stations. | 1868-9 | 1869-70 | 1870-1 | 1871-2 | 1872-3 | 1873-4 |
|---|---|---|---|---|---|---|
| Port Blair, ............... | + 2·0 | + 4·0 | | | + 2·5 | + 1·5 |
| Cuttack, ............... | | | + 1·5 | + 5·2 | 0 | — 4·4 |
| Chittagong, ............ | | | — 4·2 | — 4·8 | 0 | — 1·3 |
| Jessore, ............... | | + 2·7 | | | | |
| Dacca, ................. | | | — 0·6 | +0·9 | + 0·4 | — 5·9 |
| Hazaribaore, ............ | + 1·5 | + 0·5 | | | — 2·0 | — 0·5 |
| Berhamp ............... | + 1·2 | | — 3·5 | | —12·5 | — 9·0 |
| Silchar, ............... | | | — 2·5 | 0 | — 3·0 | +14·0 |
| Monghyr, ............... | + 5·0 | — 1·5 | — 2·5 | | | |
| Patna, ................. | — 3·0 | | | | | |
| Roorkee, ............... | | — 6·0 | + 3·5 | | — 8·9 | + 0·7 |
| Sums, | + 6·7 | — 0·3 | — 8·3 | + 1·3 | —23·5 | — 4·9 |
| Means, | + 1·3 | — 0·1 | — 1·0 | + 0·3 | — 2·9 | — 0·6 |

TABLE IV. B.—*Mean monthly and annual differences of maximum black-bulb temperatures.*

| MONTHS. | 1868-9. | 1869-70. | 1870-1. | 1871-2. | 1872-3. | 1873-4. |
|---|---|---|---|---|---|---|
| January, | + 5·0 | — 0·2 | — 1·3 | — 2·3 | + 2·5 | — 4·7 |
| February, | +10·8 | — 2·9 | — 0·8 | — 3·7 | + 2·1 | — 3·1 |
| March, | + 5·7 | + 6·4 | — 0·8 | — 0·2 | — 2·2 | — 3·2 |
| April, | + 4·2 | + 0·9 | + 0·6 | — 2·6 | — 3·7 | — 0·5 |
| May, | + 4·0 | + 3·9 | + 2·5 | — 0·1 | — 0·3 | — 0·5 |
| June, | + 3·9 | + 7·6 | — 1·2 | + 2·7 | + 0·9 | — 1·1 |
| July, | — 2·8 | + 2·7 | — 0·2 | + 2·8 | — 0·2 | + 1·5 |
| August, | + 8·0 | — 1·3 | — 0·9 | + 0·6 | — 0·4 | + 0·6 |
| September, | + 3·3 | — 1·9 | — 0·9 | + 3·4 | — 2·9 | + 2·8 |
| October, | + 0·7 | + 3·5 | — 0·3 | — 0·9 | — 1·1 | + 2·7 |
| November, | — 2·5 | — 2·9 | — 3·9 | + 4·9 | — 3·3 | + 3·2 |
| December, | + 1·3 | — 0·1 | — 1·0 | + 0·3 | — 2·9 | — 0·6 |
| Yearly sums, | +41·6 | +21·5 | —11·6 | — 0·5 | —11·5 | — 2·9 |
| Means, | + 3·5 | + 1·6 | — 0·9 | 0 | — 0·9 | — 0·2 |

The results obtained by these four different methods, resting on two distinct kinds of data, agree then, in shewing a very decided variation of the incident solar heat; a variation which, in the epoch of its maximum approximately, its rapid rise before that maximum and slower decline after it, agrees with the variation curve of the solar spots. Table III being based on a far larger quantity of data than either of the others, probably gives the most trustworthy results. The curve obtained from this table is given in the adjoining figure.



What proportion the variation may bear to the total incident heat, the present data of course cannot show ; and in order to know this, we must await the regular actinometric observations which it is to be hoped may be undertaken at the new Solar Observatory under Col. Tennant at Simla. But judging from the present results, it would certainly appear probable that the variation is such as must exercise a very appreciable influence on the Meteorology of our earth. "It is a dynamical law absolutely universal and one which extends beyond the domain of mere dynamics, that all periodicity in the action of a cause, propagates itself into every, even the remotest effect of that cause, through whatever chain of intermediate arrangements the action is carried out."*

If then the sun's radiation vary directly with the number of the spots and prominences, every other meteorological phenomenon must likewise so vary, rainfall and temperature included, and we have therefore *a priori* grounds for the validity of Meldrum, Lockyer, and Köppen's discoveries. With regard to the rainfall, the coincidence of its variation with that of the sun spots has been only partially verified by the data ; but seeing that the rainfall of the larger part of the world has not been taken into consideration in the comparison, this is no more than we should expect. In India, for instance, the registers of most of the few stations that have been compared, fail to conform to the supposed law, but India is but a small part of the region on which precipitation takes place during the SW. monsoon, and I have shewn in a former volume of this Journal, that there are independent grounds for believing, that owing to protracted variations in the distribution of atmospheric pressure in different years, (from what causes arising we are at present unable to determine,) deficient rainfall in one part of the monsoon area is probably compensated in great part by an excessive rainfall elsewhere. As far as the coincidence has been established, the quantity of rain that falls, varies directly with the intensity of the sun's radiation ; in other words, with the quantity of energy received from the sun, which of course determines the quantity of water evaporated and afterwards condensed.

This consideration appears to me to throw some light on the apparently anomalous variation of temperature detected by Professor Köppen.† He finds that, in the tropics, the maximum temperature coincides, not with the maximum of the sun-spots, but more nearly with their minimum ; which, however, it precedes by ½ to 1½ years. His inference, partly based on this fact, and partly on his erroneous idea of the nature of the spots, is the reverse of that which follows from the facts now adduced. He concludes that the spots are an indication of the diminished radiation of the sun,

* Herschel's 'Meteorology,' p. 137.

† Zeitsch. d. Oesterr. Gesellschaft für Meteorologie, Vol. VIII, pp. 241 and 257.

and adopts the earlier hypothesis of De la Lande and of Zöllner that they are solidified scoriaceous masses floating on the glowing fluid surface ["Schollen fest-gewordener Stoffe auf der glühendflüssigen Sonnenkugel"]. The great discovery of Chacornac and Lockyer in 1865, that the spots are produced by a down-rush of the cooled external atmosphere of the sun, would seem to be unknown to him.

The spots being then, in all probability, an indication of increased radiation, how is this to be reconciled with the facts ascertained by Professor Köppen. Possibly, I think, in this way. The temperatures dealt with by Professor Köppen are of course those of the lowest stratum of the atmosphere at land stations ; and must be determined, not by the quantity of heat that falls on the exterior of the planet, but on that which penetrates to the earth's surface, chiefly to the land surface of the globe. The greater part of the earth's surface being, however, one of water, the principal immediate effect of the increased heat must be to increase the evaporation, and therefore, as a subsequent process, the cloud and the rainfall. Now a cloudy atmosphere intercepts the greater part of the solar heat ; and the re-evaporation of the fallen rain lowers the temperature of the surface from which it evaporates and that of the stratum of the air in contact with it. The heat liberated by cloud condensation doubtless raises the temperature of the air at the altitude of the cloudy stratum ; but, at the same time, we have two causes at work, equally tending to depress that of the lowest stratum. As a consequence, an increased formation of vapour, and therefore of rain, following on an increase of radiation, might be expected to coincide with a low air-temperature on the surface of the land.

It is needless to point out that a vast train of enquiry is opened up by the fact, once established, that the solar heat undergoes a periodical variation. It is I believe of high importance to Meteorology, or will be so when the amount of the variation shall have been ascertained in terms of absolute measurement, and it affords a strong additional incentive to the establishment of an observatory in India, such as have already been founded under the less favoured skies of Germany and on the Rocky mountains, for observing and measuring the variations of the sun. These and their immediate effects are, by prerogative, the study of the tropics.

P. S. *July* 12*th*.—Since the foregoing paper was read, I have examined the register of Darjiling ; a station which, although frequently obscured by cloud, has the advantage over stations on the plains, that it is above the level of the dust haze that absorbs so much of the solar heat over the latter. I have discussed the registers by a method somewhat different from either of those followed in the body of the paper, *viz.*, by selecting the three highest recorded sun temperatures in each half month, deducting from each the maximum temperature of the air in the shade on the same days, and taking the mean of the six differences to represent the solar intensity of the month. The result, as will be seen from the following table, is in complete accordance with that previously arrived at from other data. The same thermometer has been in use throughout.

TABLE V.—*Solar intensity at Darjiling.*

| STATIONS. | 1870. | 1871. | 1872. | 1873. | 1874. | 1875. |
|---|---|---|---|---|---|---|
| January, .. .. | | 57·8 | 67·7 | 59·2 | 57·8 | 62·3 |
| February, .. .. | | 62·2 | 62·8 | 62·3 | 56·5 | 60·3 |
| March, .. .. | | 63·3 | 63·5 | 62· | 58·2 | 57·8 |
| April, .. .. | | 64·2 | 63·2 | 62·8 | 55·7 | 60·2 |
| May, .. .. | 62·2 | 67·8 | 66·8 | 63·8 | 59·8 | |
| June, .. .. | 67· | 68· | 67·3 | 62·5 | 59·2 | |
| July, .. .. | 63·3 | 66·2 | 65·7 | 60·8 | 56·3 | |
| August, .. .. | 70·8 | 65·7 | 66·8 | 60· | 57·8 | |
| September, .. .. | 71·5 | 69·3 | 63·7 | 62·3 | 59·3 | |
| October, .. .. | 65·5 | 68·2 | 70· | 63·3 | 60·8 | |
| November, .. .. | 62·5 | 67·3 | 62·5 | 57·3 | 63·3 | |
| December, .. .. | 59· | 66·3 | 59· | 53·8 | 60·5 | |
| Year, .. | | 65·5 | 64·9 | 60·8 | 58·6 | |

## VII.—*Notes on the Geology of part of the Dafla Hills, Assam; lately visited by the Force under Brigadier-General* STAFFORD, *C. B.—By Major* H. H. GODWIN-AUSTEN, *F. R. G. S., F. Z. S., &c., Deputy Superintendent Topographical Survey of India.*

(Received June 18th,—Read July 7th, 1875.)

(With Plate VI.)

My survey duties with the late expedition into the portion of the Eastern Himalaya known as the Dafla Hills gave me an opportunity of making a few notes on the geology of this portion of the North-eastern frontier, of which so little is known up to the present time.

From the Brahmaputra near Bishnáth and Dunsiri Mukh, the outer range of the Tertiary sandstones is well seen, the steep scarps shewing white against the dense forest with which they are covered. I first entered this outer range by a route up the bed of the Darpang stream, a tributary of the Pichola, when proceeding to clear the hill Dihirhi Párbat for a Trigonometrical station. After leaving Borpathar, the road leads over the plain in a direction WNW., and after 5 miles the shallow bed of the Darpang is followed up and leads directly by a narrow gorge into the hills: these rise suddenly from the level plain of recent detritus, no outlying beds of later age being seen here.